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Hayashi et al.

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(54) **LIGHTING CIRCUIT FOR LIGHT EMITTING ELEMENT AND ILLUMINATION APPARATUS INCLUDING SAME**

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H05B 41/14 (2006.01)
H05B 37/02 (2006.01)
H05B 33/08 (2006.01)

(52) **U.S. Cl.**
CPC ***H05B 37/02*** (2013.01); ***H05B 33/08*** (2013.01); ***H05B 33/0818*** (2013.01)

(58) **Field of Classification Search**
CPC H05B 41/3927; H05B 33/0809; H05B 33/0842; H05B 41/2824; H05B 41/2828
See application file for complete search history.

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(57) **ABSTRACT**

A light-emitting-element lighting circuit for dimming a light emitting element by a PWM dimming signal of a duty ratio corresponding to an input dimming signal is provided. The lighting circuit includes a PWM dimming signal generating unit which generates the PWM dimming signal by performing a summation of AC wave signals including a fundamental wave and harmonics of different frequencies that are integer multiples of a fundamental frequency of the fundamental wave. The fundamental frequency is equal to or higher than a frequency, at which a sound pressure level is at maximum, in an audible frequency range in a correlation spectrum between the sound pressure level generated from the light emitting element and a frequency of an AC wave signal inputted to the light emitting element.

5 Claims, 6 Drawing Sheets

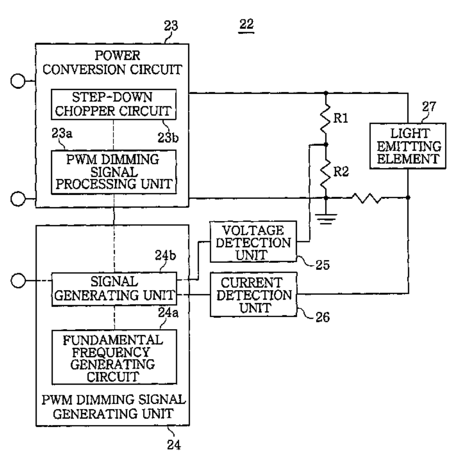

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FIG. 1A

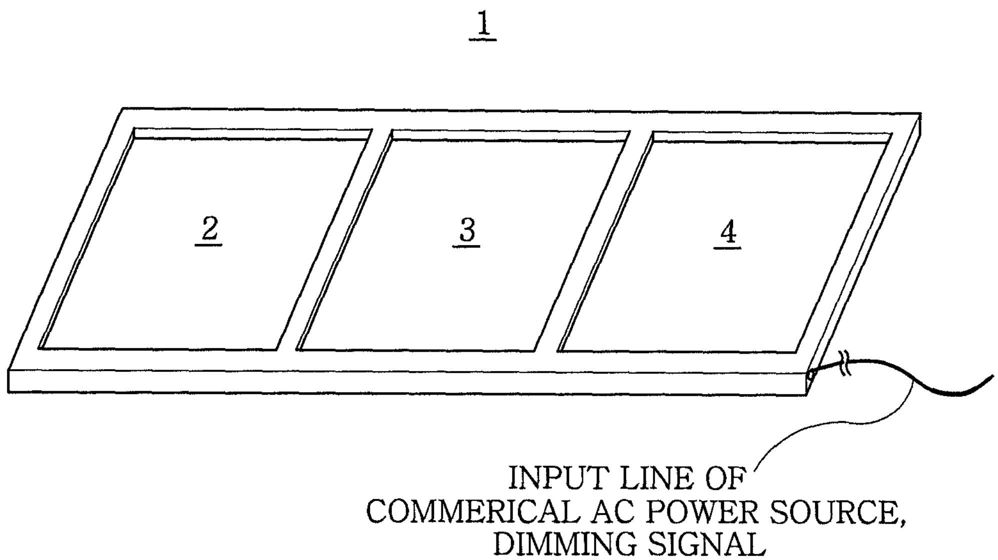

1
2
3
4
INPUT LINE OF
COMMERICAL AC POWER SOURCE,
DIMMING SIGNAL

FIG. 1B

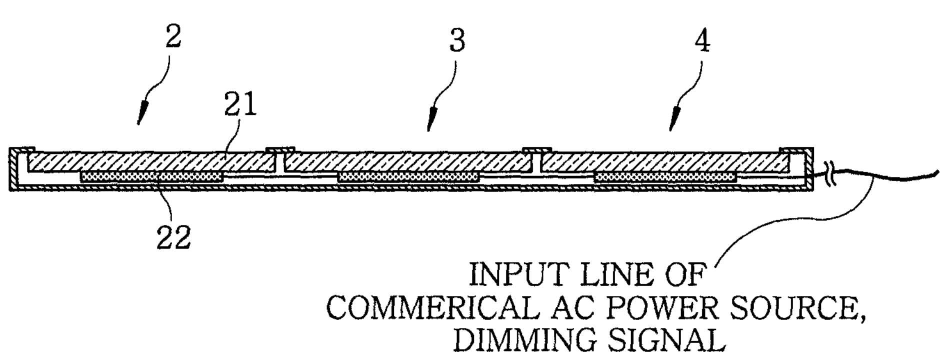

2
3
4
21
22
INPUT LINE OF
COMMERICAL AC POWER SOURCE,
DIMMING SIGNAL

FIG. 2

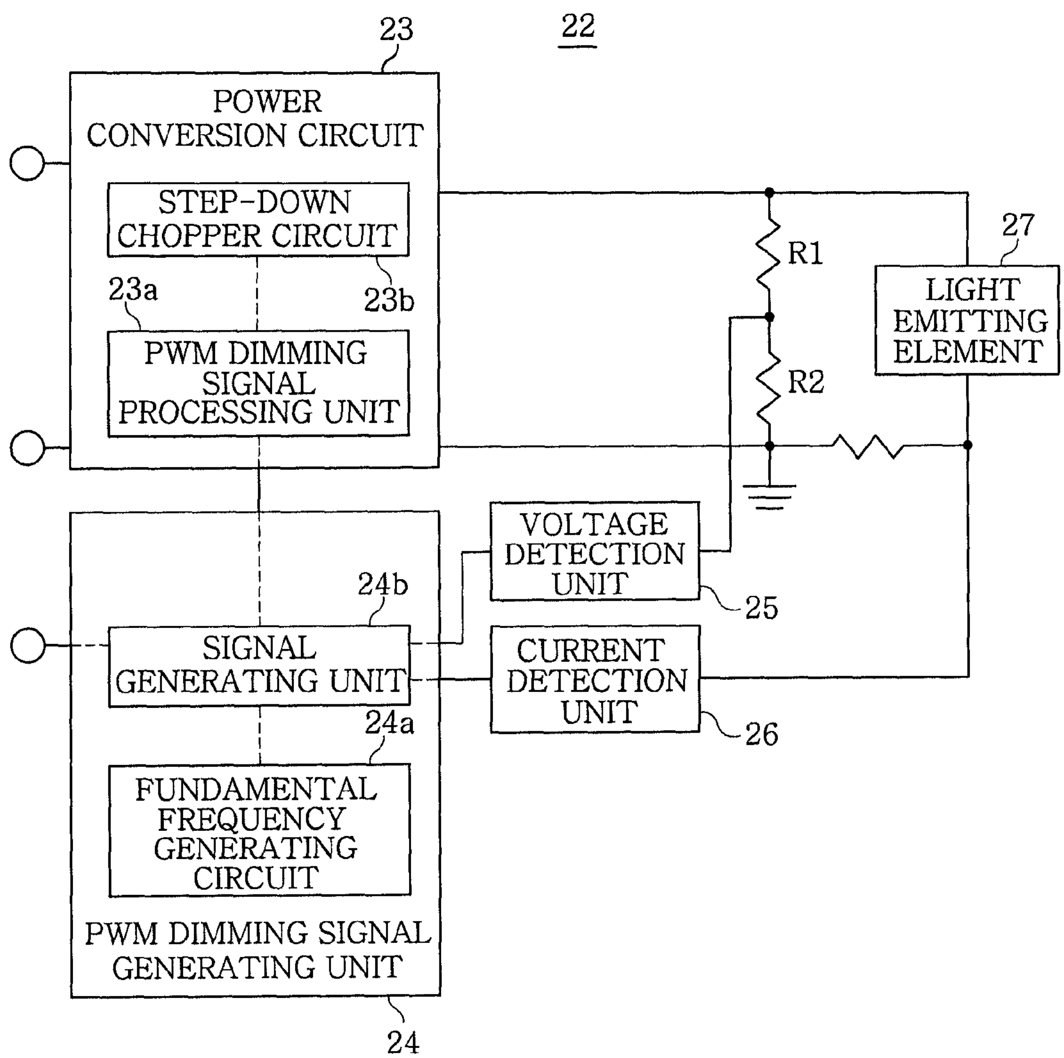
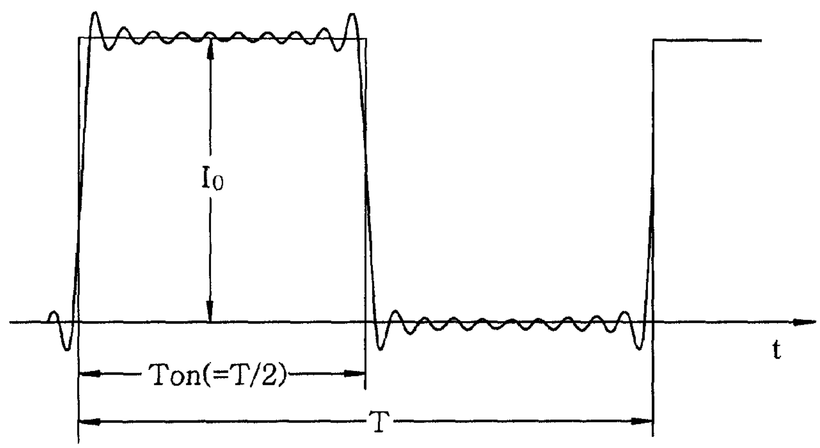
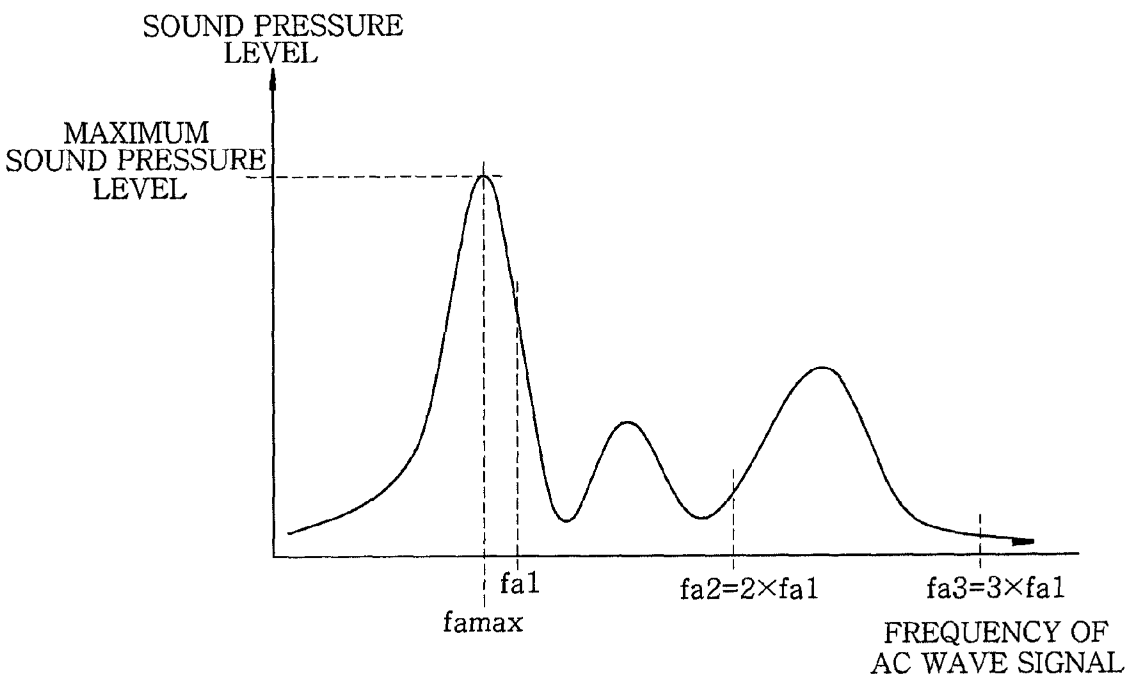

23
22
POWER CONVERSION CIRCUIT
STEP-DOWN CHOPPER CIRCUIT
23a
23b
PWM DIMMING SIGNAL PROCESSING UNIT
R1
R2
27
LIGHT EMITTING ELEMENT
VOLTAGE DETECTION UNIT
25
24b
SIGNAL GENERATING UNIT
CURRENT DETECTION UNIT
26
24a
FUNDAMENTAL FREQUENCY GENERATING CIRCUIT
PWM DIMMING SIGNAL GENERATING UNIT
24

FIG. 3



I_0
t
Ton(=T/2)
T

FIG. 4



SOUND PRESSURE LEVEL
MAXIMUM SOUND PRESSURE LEVEL
fa1
famax
fa2=2×fa1
fa3=3×fa1
FREQUENCY OF AC WAVE SIGNAL

FIG. 5

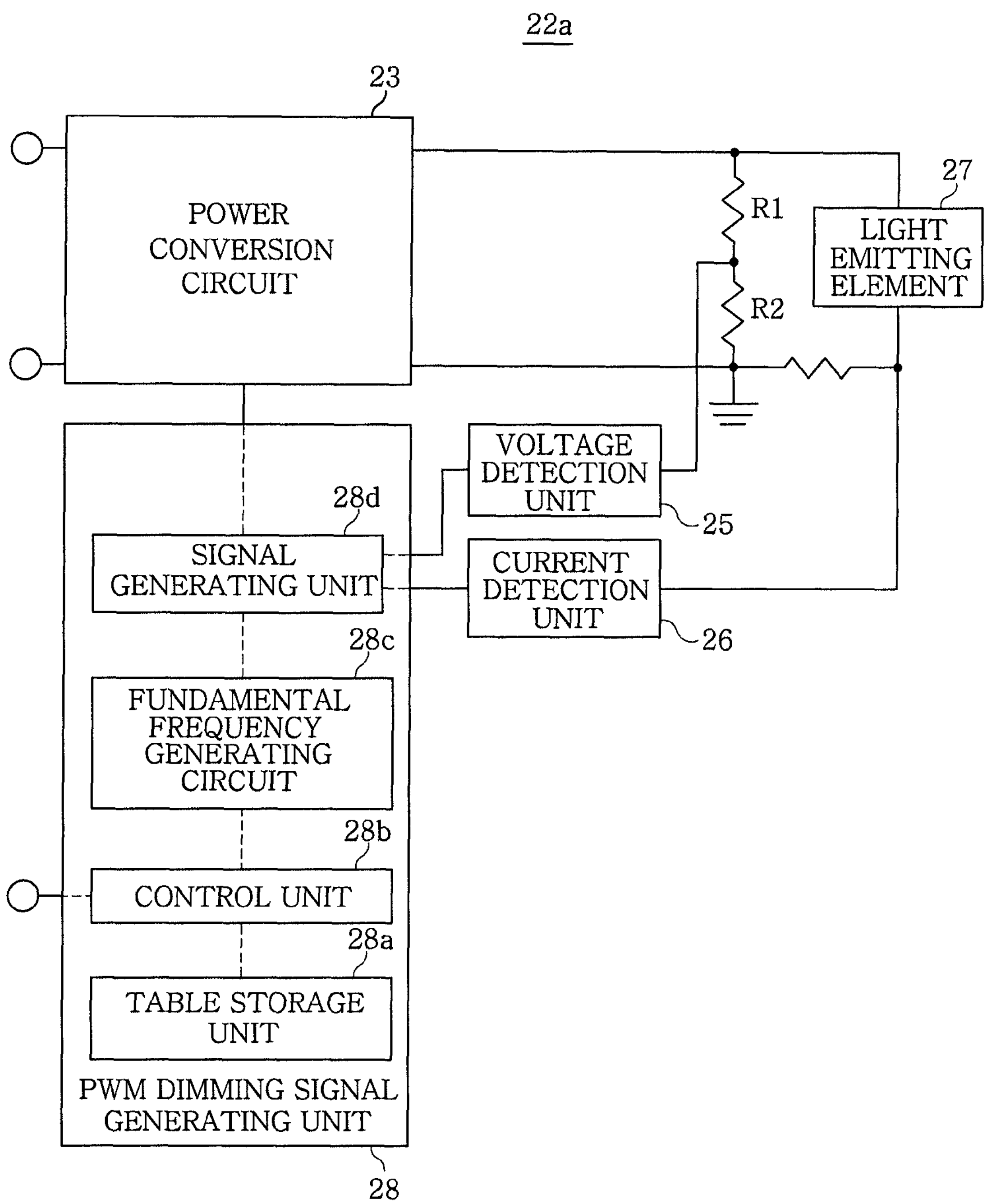

22a
23
POWER CONVERSION CIRCUIT
R1
R2
27
LIGHT EMITTING ELEMENT
VOLTAGE DETECTION UNIT
25
28d
SIGNAL GENERATING UNIT
CURRENT DETECTION UNIT
26
28c
FUNDAMENTAL FREQUENCY GENERATING CIRCUIT
28b
CONTROL UNIT
28a
TABLE STORAGE UNIT
PWM DIMMING SIGNAL GENERATING UNIT
28

FIG.6

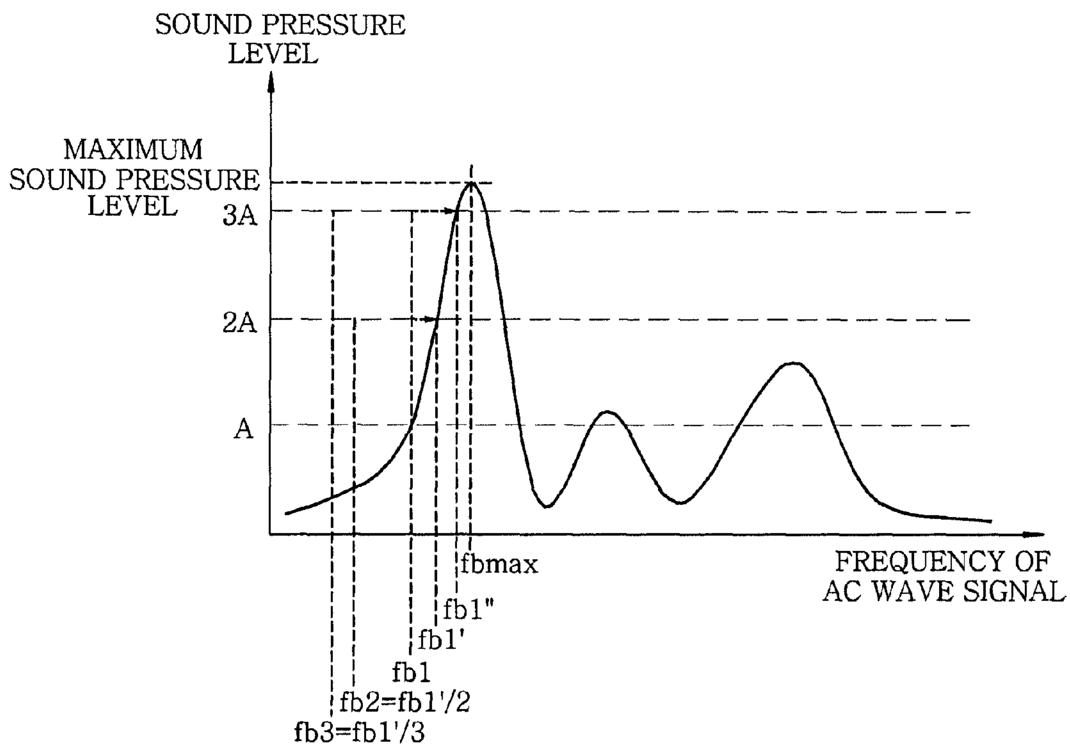

SOUND PRESSURE LEVEL
MAXIMUM SOUND PRESSURE LEVEL
3A
2A
A
fbmax
fb1"
fb1'
fb1
fb2=fb1'/2
fb3=fb1'/3
FREQUENCY OF AC WAVE SIGNAL

FIG. 7A

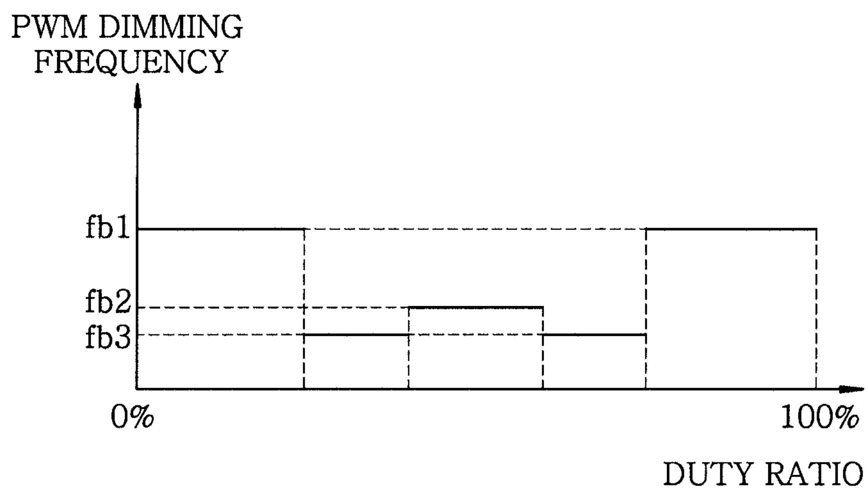
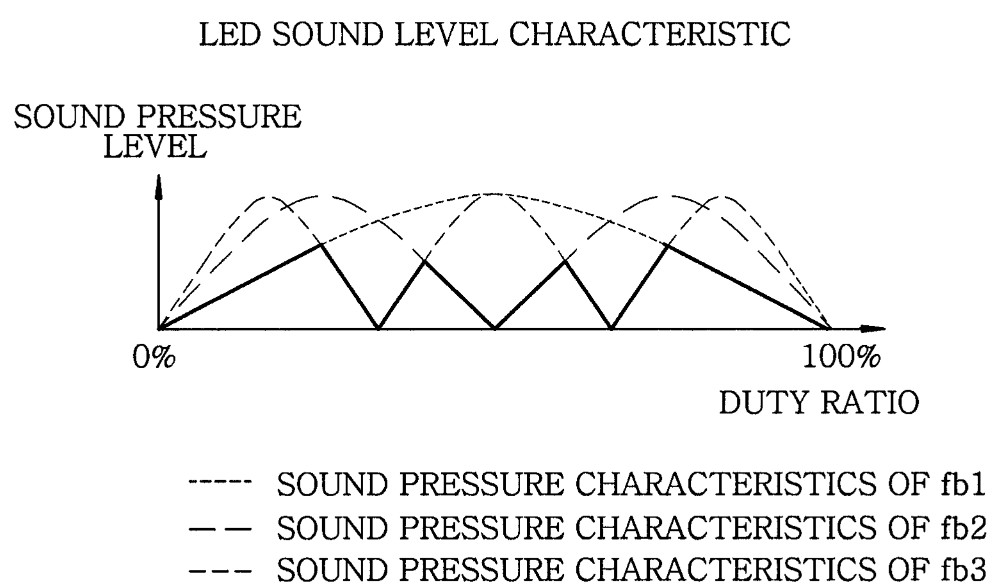

PWM DIMMING FREQUENCY
fb1
fb2
fb3
0%
100%
DUTY RATIO

FIG. 7B


LED SOUND LEVEL CHARACTERISTIC
SOUND PRESSURE LEVEL
0%
100%
DUTY RATIO
SOUND PRESSURE CHARACTERISTICS OF fb1
SOUND PRESSURE CHARACTERISTICS OF fb2
SOUND PRESSURE CHARACTERISTICS OF fb3

LIGHTING CIRCUIT FOR LIGHT EMITTING ELEMENT AND ILLUMINATION APPARATUS INCLUDING SAME

FIELD OF THE INVENTION

The present invention relates to a lighting circuit for a light emitting element such as an organic electroluminescence (EL) element or the like, and an illumination apparatus including the lighting circuit.

BACKGROUND OF THE INVENTION

Conventionally, there has been known a lighting circuit for a light emitting element such as an organic EL element or the like, which is configured to generate a PWM dimming signal having a duty ratio corresponding to a light emission level specified by a dimming signal, and perform the dimming control.

For example, Japanese Patent Application Publication No. 2009-54425 describes a lighting circuit configured to perform a so-called burst dimming to stop the light emission of the light emitting element during the OFF period of the PWM dimming signal.

For example, in case of using an organic EL element as the light emitting element, it is problematic that audible sound (noise) is generated from the light emitting element when the frequency of a signal for performing the burst dimming is about 1 kHz. The organic EL element has a larger light emitting area compared to, e.g., a light emitting diode (LED), and thus the audible sound tends to increase.

Generally, the audible frequency range is from 20 Hz to 20 kHz. Thus, it is conceivable to operate the light emitting element by using a signal of a frequency exceeding the audible frequency range, e.g., a frequency of 20 kHz or more. However, it is difficult and expensive to stably operate the circuit which generates such inaudible high frequency signal.

SUMMARY OF THE INVENTION

In view of the above, the present invention provides a lighting circuit for a light emitting element which performs a burst dimming and suppresses a generation of audible sound from the light emitting element.

In accordance with an aspect of the present invention, there is provided a light-emitting-element lighting circuit for dimming a light emitting element by a PWM dimming signal of a duty ratio corresponding to an input dimming signal, the lighting circuit including: a PWM dimming signal generating unit which generates the PWM dimming signal by performing a summation of AC wave signals including a fundamental wave and harmonics of different frequencies that are integer multiples of a fundamental frequency of the fundamental wave.

Further, the fundamental frequency may be equal to or higher than a frequency, at which a sound pressure level is at maximum in an audible frequency range, in a correlation spectrum between the sound pressure level generated from the light emitting element and a frequency of an AC wave signal inputted to the light emitting element.

Further, the fundamental frequency may be lower than a frequency, at which a sound pressure level is at maximum in an audible frequency range, in a correlation spectrum between the sound pressure level generated from the light emitting element and a frequency of an AC wave signal inputted to the light emitting element.

Further, the fundamental frequency and a frequency of at least one of the harmonics are included in the audible frequency range.

Further, the PWM dimming signal may be represented by the following equation:

$$I = I_0 \cdot \frac{T_{on}}{T} + I_0 \sum \frac{2}{n\Pi} \sin\left(n\Pi \frac{T_{on}}{T}\right) \cos(2n\pi f t),$$

where I_0 is a maximum amplitude value of a current, n is an integer equal to or greater than 1, and Ton/T is an ON duty ratio of a square wave.

Further, the light emitting element may be an organic electroluminescence (EL) light emitting element.

Further, the fundamental frequency may be provided in a plural number, and one of the plurality of the fundamental frequencies is selected for each duty ratio corresponding to the input dimming signal.

In accordance with another aspect of the present invention, there is an illumination apparatus including: one or more illumination panels, each having a light emitting element; and the lighting circuit described above for lighting the light emitting element.

In accordance with the light-emitting-element lighting circuit or the illumination apparatus of the present invention, the fundamental frequency to be used is equal to or higher than the frequency at the maximum sound pressure level in the audible frequency range, and the sound pressure levels at the frequencies of the harmonics do not exceed the maximum sound pressure level. Therefore, the total sound pressure level becomes low when generated by using the PWM dimming signal of the square wave obtained by the summation of AC wave signals including the fundamental wave and harmonics of different frequencies that are integer multiples of the fundamental frequency of the fundamental wave. As a result, in the light-emitting-element lighting circuit which performs the burst dimming and the illumination apparatus, it is possible to suppress the generation of the audible sound from the light emitting element without using a high fundamental frequency exceeding the audible frequency range.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects and features of the present invention will become apparent from the following description of embodiments, given in conjunction with the accompanying drawings, in which:

FIGS. **1**A and **1**B show an illumination apparatus having a lighting circuit for a light emitting element in accordance with a first embodiment of the present invention, wherein FIG. **1**A is a perspective view of the illumination apparatus, and FIG. **1**B is a cross-sectional view of the illumination apparatus;

FIG. **2** is a circuit diagram of the lighting circuit for the light emitting element in accordance with the first embodiment of the present invention;

FIG. **3** shows an example of a PWM dimming signal;

FIG. **4** is a graph showing a correlation spectrum between a sound pressure level of audible sound generated from the light emitting element and a frequency of an AC wave signal inputted to the light emitting element;

FIG. **5** is a circuit diagram of a lighting circuit for a light emitting element in accordance with a second embodiment of the present invention;

FIG. **6** is a graph showing a correlation spectrum between a sound pressure level of audible sound generated from the light emitting element and a frequency of an AC wave signal inputted to the light emitting element; and

FIG. **7**A illustrates frequencies selected for individual duty ratios, and FIG. **7**B shows a relationship between the sound pressure level and the fundamental wave, the second harmonic, and the third harmonic.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The present invention will now be described with reference to embodiments shown in the accompanying drawings which form a part hereof.

A lighting circuit for a light emitting element of an illumination apparatus in accordance with embodiments of the present invention is a circuit which performs a burst dimming of a light emitting element such as an organic electroluminescence (EL) element based on a PWM dimming signal of a duty ratio corresponding to a dimming signal inputted from a controller which sets a dimming level. The lighting circuit for a light emitting element includes a PWM dimming signal generating unit for generating the PWM dimming signal by performing a summation (operation represented by "Σ") of AC wave signals including a fundamental wave and harmonics of different frequencies that are integer multiples of the fundamental frequency of the fundamental wave. The PWM dimming signal generating unit uses the fundamental frequency at which a sound pressure level generated from the light emitting element is low. The fundamental frequency is a frequency within the audible frequency range determined in advance based on a correlation spectrum between the sound pressure level generated from the light emitting element and a frequency of an AC wave signal inputted to the light emitting element.

First Embodiment

FIGS. **1**A and **1**B show an illumination apparatus **1** in accordance with a first embodiment of the present invention. FIG. **1**A is a perspective view of the illumination apparatus **1** fixed to a ceiling, wall, floor, stand or the like. The illumination apparatus **1** includes three light emitting panels **2**, **3** and **4**, each having a light emitting surface oriented upward in FIG. **1**A. FIG. **1**B is a cross-sectional view of the illumination apparatus **1**. The light emitting panels **2**, **3** and **4** have the same configuration.

In the following, a description will be made using the light emitting panel **2** as an example. The light emitting panel **2** includes an organic EL light emitting element **21** and a light-emitting-element lighting circuit (hereinafter, simply referred to as lighting circuit) **22** which performs a burst dimming of the light emitting element **21**. The lighting circuit **22** is connected to a commercial AC power source having a frequency of 50 Hz or 60 Hz, and a cable to which the dimming signal is inputted. The dimming signal is a signal which specifies light emission levels of a plurality of gradations and is outputted in response to the operation of, e.g., a sliding or rotary controller (not shown).

The lighting circuit **22** generates a PWM modulation signal of a duty ratio corresponding to the light emission level specified by the dimming signal, and performs the burst dimming of the light emitting element based on the ON period and OFF period of the PWM modulation signal.

FIG. **2** is a circuit diagram of the lighting circuit **22**. The lighting circuit **22** includes a power conversion circuit **23**, a PWM dimming signal generating unit **24**, a voltage detection unit **25**, a current detection unit **26**, and an organic EL light emitting element **27**.

The power conversion circuit **23** converts an input voltage from the commercial AC power source into a DC application voltage for the burst dimming of the light emitting element **27** to output the DC application voltage to the light emitting element **27**. The application voltage is a square pulse signal having ON and OFF periods in which the light emitting element **27** is turned on and off at a specific duty ratio. The power conversion circuit **23** includes a PWM dimming signal processing unit **23***a*, and a step-down chopper circuit **23***b*. During the ON period of the PWM dimming signal inputted from the PWM dimming signal generating unit **24**, the PWM dimming signal processing unit **23***a* generates a drive signal (a chopper signal) for driving the step-down chopper circuit **23***b* and outputs the drive signal to a drive transistor (not shown) of the step-down chopper circuit **23***b*.

The PWM dimming signal generating unit **24** includes a fundamental frequency generating circuit **24***a* and a signal generating unit **24***b*. The fundamental frequency generating circuit **24***a* generates a signal of the fundamental wave of the fundamental frequency, which will be described later, and outputs the signal to the signal generating unit **24***b*. The signal generating unit **24***b* generates the PWM dimming signal of a duty ratio corresponding to the dimming signal, and outputs the PWM dimming signal to the power conversion circuit **23**. First, the signal generating unit **24***b* performs a summation of AC wave signals including a fundamental wave and harmonics, the harmonics having different frequencies that are integer multiples (2, 3, . . .) of the fundamental frequency of the fundamental wave and amplitudes obtained by dividing an amplitude of the fundamental wave by the values of the corresponding integer multiples. The signal generating unit **24***b* outputs the signal, obtained by the summation whose potential at a low level is set to 0 V, as the PWM dimming signal. The voltage detection unit **25** detects the voltage applied to the light emitting element **27** through a voltage divider circuit including resistors R**1** and R**2** connected in series. The current detection unit **26** detects a current flowing through the light emitting element **27**. The PWM dimming signal generating unit **24** performs a feedback control process such that the voltage applied to the light emitting element **27** becomes a desired value based on the detection values obtained by the voltage detection unit **25** and the current detection unit **26**.

FIG. **3** shows an example of the PWM dimming signal of a square wave having a duty ratio of 50%. For example, the PWM dimming signal is given by the following equation:

$$I = I_0 \cdot \frac{T_{on}}{T} + I_0 \sum \frac{2}{n\pi} \sin\left(n\pi \frac{T_{on}}{T}\right) \cos(2n\pi f t), \qquad \text{Eq. 1}$$

where I_0 is a maximum amplitude value of the current, n is an integer equal to or greater than 1, and Ton/T is an ON duty ratio of the square wave.

The first term in Eq. 1 is a term for setting the potential of the PWM dimming signal at a low level to 0 V.

FIG. **4** is a graph showing a correlation spectrum (sound pressure characteristics) between a sound pressure level of audible sound generated from the light emitting element **27** and a frequency of an AC wave signal having no accompanying harmonics inputted to the light emitting element **27**. The human audible frequency range is generally from 20 Hz to 20 kHz. The light emitting element **27** has specific oscillation characteristics due to its structure. Therefore, it is preferable that the correlation spectrum is investigated for the light emitting element **27** that is actually installed in the lighting circuit **22**. However, there may be used the statistical data obtained by investigating multiple light emitting elements having the same configuration as the light emitting element **27**. The sound pressure level is measured by using, for example, a sound level meter equipped with a frequency weighting filter that tends to represent the frequency characteristic of A-weighting curve or its equivalent or more among ordinary sound level meters specified by JISC1502.

From the graph shown in FIG. **4**, the sound pressure level is maximum at a frequency famax. For example, the frequency famax of the organic EL light emitting element used in the experiment was 1.5 kHz. Hereinafter, the sound pressure level at a frequency famax is referred to as a maximum sound pressure level. The PWM dimming signal generating unit **24** uses a frequency fa**1** equal to or higher than the frequency famax as the fundamental frequency. Further, generally, as the fundamental frequency is lowered, it is easier to control and the circuit cost is also lowered. Thus, the frequency fa**1** is equal to or slightly greater than the frequency famax, and is set such that the frequency of a harmonic that is an integer multiple of the fundamental frequency, e.g., the third harmonic, preferably, the fifth harmonic, more preferably, the seventh or higher harmonic is equal to or less than 20 kHz.

Next, description will be made in case where the PWM dimming signal is generated by using harmonics (the second harmonic and the third harmonic) of a frequency fa**2** that is twice the fundamental frequency and a frequency fa**3** that is three times the fundamental frequency in addition to the fundamental frequency fa**1** (fundamental wave). The sound pressure level generated from the light emitting element **27** by the second harmonic and the third harmonic is lower than the maximum sound pressure level even in case of having the same amplitude. Further, in Eq. 1, maximum amplitudes of the second harmonic and the third harmonic are set to be ½ and ⅓ of the signal of the fundamental frequency, respectively. As a result, the sound pressure level of the audible sound generated from the light emitting element **27** can be suppressed to a low level.

As described above, in the lighting circuit **22** which performs the burst dimming and the illumination apparatus **1** having the lighting circuit **22** in accordance with the first embodiment of the present invention, the fundamental frequency to be used is equal to or higher than the frequency at the maximum sound pressure level in the audible frequency range. For this reason, the sound pressure levels even at the frequencies of the harmonics do not exceed the maximum sound pressure level. Therefore, the total sound pressure level becomes low when generated by using the PWM dimming signal of the square wave obtained by the summation of AC wave signals including the fundamental wave and harmonics of different frequencies that are integer multiples of the fundamental frequency of the fundamental wave. As a result, in the lighting circuit **22** which performs the burst dimming and the illumination apparatus **1** having same, it is possible to suppress the generation of the audible sound from the light emitting element without using a high fundamental frequency exceeding the audible frequency range.

Second Embodiment

The lighting circuit in accordance with a second embodiment of the present invention is configured to switchably use a plurality of fundamental frequencies, and generate the PWM dimming signal by selecting the fundamental frequency, at which the sound pressure level of the audible sound is the lowest, for each duty ratio corresponding to the input dimming signal.

FIG. **5** is a circuit diagram of a light-emitting-element lighting circuit **22***a* in accordance with a second embodiment of the present invention. The same reference numerals will be given to the same components as those of the light emitting element lighting circuit **22** in accordance with the first embodiment of the present invention, and a redundant description will be omitted. The lighting circuit **22***a* includes the power conversion circuit **23**, a PWM dimming signal generating unit **28**, the voltage detection unit **25**, the current detection unit **26**, and the light emitting element **27**.

The PWM dimming signal generating unit **28** includes a table storage unit **28***a*, a control unit **28***b*, a fundamental frequency generating circuit **28***c*, and a signal generating unit **28***d*. The control unit **28***b* specifies the fundamental frequency corresponding to the duty ratio determined by the input dimming signal from a look-up table stored in the table storage unit **28***a*. The fundamental frequency generating circuit **28***c* generates a signal of the fundamental frequency specified by the control unit **28***b*, and outputs the signal to the signal generating unit **28***d*. The signal generating unit **28***d* performs a summation of AC wave signals including a fundamental wave and harmonics having frequencies that are integer multiples (2, 3, . . .) of the fundamental frequency of the fundamental wave and amplitudes obtained by dividing the amplitude of the fundamental wave by the values of the corresponding integer multiples. By performing such summation, the signal generating unit **28***d* generates and outputs the PWM dimming signal of a duty ratio determined by the control unit **28***b* to the power conversion circuit **23** after setting a potential of the PWM dimming signal at a low level to 0 V. (see Eq. 1).

The look-up table is a table specifying the fundamental frequency corresponding to each duty ratio on a one-to-one basis, and is created by the following steps **1** to **3**. FIG. **6** is a graph showing a correlation spectrum (sound pressure characteristics) between a sound pressure level of the audible sound generated from the light emitting element and a frequency of an AC wave signal having no accompanying harmonics inputted to the light emitting element **27**. FIG. **6** explains a method to specify the first to third fundamental frequencies. Hereinafter, the steps for creating the look-up table will be described with reference to FIG. **6**.

First, in step **1**, in the graph shown in FIG. **6**, a first frequency fb**1** is referred to as a frequency lower than a frequency fbmax at which the sound pressure level of the audible sound is at maximum.

Secondly, in step **2**, a frequency value of 1/m times a frequency, at which a sound pressure level of m times (m is an integer of 2 or more) a sound pressure level A at the first frequency fb**1** is generated, is defined as an m-th frequency. If a value of m is 2 or 3, a frequency, at which a sound pressure level **2**A that is twice the sound pressure level A is generated, is represented by fb**1'** or a frequency, at which a sound pressure level **3**A that is three times the sound pressure level A is generated, is represented by fb**1"**. The second frequency fb**2** is set to fb**1"**/2, and the third frequency fb**3** is set to fb**1"**/3 (see FIG. **6**). A case where the value of m is 2 and 3 will be described below.

In step **3**, in the case of using each of the first to third frequencies fb**1**, fb**2** and fb**3** as the fundamental frequency, the frequency, at which the sound pressure level is the lowest in each duty ratio within a range of use, is determined as the fundamental frequency corresponding to each duty ratio on a one-to-one basis. In this process, it is assumed that the maximum sound pressure level is the same in case of using each of the first to m-th frequencies as the fundamental frequency, and, in the correlation spectrum, a value obtained by dividing a sound pressure level at a frequency of harmonic that is (m+n) times the m-th frequency by (m+n) (n is a natural number) is less than the sound pressure level at the first frequency.

FIGS. **7**A and **7**B are graphs for explaining a process performed in the step **3**. FIG. **7**A illustrates a one-to-one correspondence relationship between the fundamental frequency and the duty ratio of the PWM dimming signal. The correspondence relationship shown in FIG. **7**A is stored as a look-up table in the table storage unit **28***a*. In the graph shown in FIG. **7**B, when considering the fundamental wave (i.e., the fundamental wave of the first frequency fb**1**), the second harmonic (i.e., the wave of the frequency fb**1'** which is the second harmonic of the second frequency fb**2**), and the third harmonic (i.e., the wave of the frequency fb**1"** which is the third harmonic of the frequency fb**3**) all of which have the same maximum sound pressure level A with respect to the duty ratio of the PWM dimming signal, the sound pressure levels of the fundamental wave, the second harmonic, and the third harmonic generated from the light emitting element **27** are represented by different dotted lines, and the lowest one of the sound pressure levels for each duty ratio is represented by a solid line.

By using the method of specifying the fundamental frequency, the frequencies fb**1**, fb**2** and fb**3**, at which the characteristics of the fundamental wave, the second harmonic, and the third harmonic appear predominantly, can be respectively selected in the relationship between the duty ratio and the sound pressure level. FIG. **7**A shows that in the case where the frequency indicated by the solid line in FIG. **7**B is the fundamental wave, the first frequency fb**1** is selected as the fundamental frequency; in the case where the frequency indicated by the solid line in FIG. **7**B is the second harmonic, the second frequency fb**2** is selected as the fundamental frequency; and in the case where the frequency indicated by a solid line in FIG. **7**B is the third harmonic, the frequency fb**3** is selected as the fundamental frequency.

With such configuration, the lighting circuit **22***a* generates the PWM dimming signal in response to the dimming signal by using the AC wave signal having the frequency, at which the sound pressure level generated from the light emitting element **27** is the lowest, as the fundamental frequency. Thus, it is possible to reduce the sound pressure level of the audible sound generated from the light emitting element **27** during the operation although the frequency lower than the frequency fbmax is set to the first frequency fb**1**.

Further, with regard to the lighting circuit **22***a*, the matters required to achieve the advantageous effects are as follows.

The lighting circuit **22***a* is a circuit for dimming the light emitting element by the PWM dimming signal of the duty ratio corresponding to the dimming signal inputted from the controller which sets the dimming level, and includes the PWM dimming signal generating unit **28** which generates the PWM dimming signal by performing the summation of AC wave signals including a fundamental wave and harmonics of different frequencies that are integer multiples of the fundamental frequency of the fundamental wave. The PWM dimming signal generating unit **28** includes the table storage unit **28***a*, the control unit **28***b*, the fundamental frequency generating circuit **28***c* and the signal generating unit **28***d*.

The look-up table stored in the table storage unit **28***a* is a table which (a) specifies a frequency at the maximum sound pressure level in the audible frequency range in the correlation spectrum between the sound pressure level generated from the light emitting element and the frequency of the AC wave signal inputted to the light emitting element, (b) sets a frequency lower than the specified frequency as the first frequency and defines a frequency value of 1/m times a frequency, at which a sound pressure level of m times (m is an integer of 2 or more) a sound pressure level at the first frequency is generated, as the m-th frequency, and (c), in the case of using each of the first to m-th frequencies as the fundamental frequency, defines the relationship between the duty ratio and the fundamental frequency specified for each duty ratio at which the sound pressure level is the lowest.

The control unit **28***b* (d) determines the fundamental frequency corresponding to the duty ratio determined by the dimming signal based on the look-up table, and (e) outputs a signal of the determined fundamental frequency from the fundamental frequency generating circuit to the signal generating unit. The signal generating unit **28***d* generates the PWM dimming signal by performing the summation of AC wave signals including a fundamental wave of the determined fundamental frequency and harmonics having frequencies that are integer multiples (2, 3, . . .) of the determined fundamental frequency and outputs the PWM dimming signal.

Further, the correlation spectrum has a waveform similar to a Gaussian function as shown in FIG. **4**. In particular, the lighting circuit operates effectively if, in the correlation spectrum, a value obtained by dividing a sound pressure level at a frequency of harmonic that is (m+n) times the m-th frequency by (m+n) is less than the sound pressure level at the first frequency.

The present invention is not limited to the configurations of the first and second embodiments and can be modified variously without departing from the spirit of the present invention. For example, in the first and second embodiments, it has been described a case where AC waves used to generate the PWM dimming signal in the PWM dimming signal generating units **24** and **28** include up to the third harmonic which is three times the fundamental frequency. However, advantageous effects can be also obtained by using AC waves including a higher harmonic than the third harmonic as long as conditions regarding the correlation spectrum are met. Further, in the second embodiment, the table storage unit **28***a*, the control unit **28***b* and the fundamental frequency generating circuit **28***c* may be realized by a hardware circuit having an equivalent function.

The light-emitting-element lighting circuit of the present invention can be used in various circuits which generate the audible sound in accordance with the burst dimming of the light emitting element.

While the invention has been shown and described with respect to the embodiments, it will be understood by those skilled in the art that various changes and modification may be made without departing from the scope of the invention as defined in the following claims.

What is claimed is:

1. A light-emitting-element lighting circuit for dimming a light emitting element by a PWM dimming signal, the lighting circuit comprising:

a PWM dimming signal generating unit adapted to generate the PWM dimming signal of a duty ratio corresponding to an input dimming signal by performing a summation of AC wave signals including a fundamental wave and harmonics that are different integer multiples of a fundamental frequency of the fundamental wave,

wherein the fundamental frequency is in an audible frequency range and is lower or higher than a frequency in the audible frequency range, at which a sound pressure level generated from the light emitting element is at maximum, and

wherein the PWM dimming signal is represented by the following equation:

$$I = I_0 \cdot \frac{T_{on}}{T} + I_0 \sum \frac{2}{n\pi} \sin\left(n\pi \frac{T_{on}}{T}\right) \cos(2n\pi f t),$$

where I_0 is a maximum amplitude value of a current, n is an integer equal to or greater than 1, and Ton/T is an ON duty ratio of a square wave.

2. The lighting circuit of claim **1**, wherein a frequency of at least one of the harmonics is included in the audible frequency range.

3. The lighting circuit of claim **1**, wherein the light emitting element is an organic electroluminescence (EL) light emitting element.

4. The lighting circuit of claim **1**, wherein the lighting circuit is adapted to select one of a plurality of frequencies lower than the frequency in the audible frequency range as the fundamental frequency to be used in the generation of the PWM dimming signal the selected one causing the light emitting element to generate a lowest sound pressure level for the duty ratio corresponding to the input dimming signal.

5. An illumination apparatus comprising:

one or more illumination panels, each having a light emitting element; and

the lighting circuit described in claim **1** for lighting the light emitting element.

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